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MEDICAL CRITERIA FOR RESPIRATORY PROTECTION IN SMOKE: THE EFFECTIVENESS OF THE MILITARY PROTECTIVE MASK

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This report summarizes the results of a study of existing information on the exposure of troops to smoke, the health hazards of the smoke, and particularly the ability of the M17 and M40 masks to protect the soldier against the hazards of exposure to military smokes and obscurants. The findings of the study are as follows: (a) the masking policy is necessary and sufficient to protect troops from the hazards of operating in smoke; (b) an alternative to the military mask for use with fog oil and diesel fuel smokes could be chosen from among the approved orinasal dust, fume, and mist respirators, but this type of protection would not be appropriate for HC, metal, or phosphorus smokes; (c) the greatest uncertainty in the assessment of health hazards from smoke and obscurants involves measurement of exposure, which determines the duration of effectiveness of the protection afforded by the mask in smoke; (d) special precautions should be taken when deploying HC smoke, which has caused fatalities when used improperly -- the masking policy must be strictly enforced, and HC should never be deployed in an enclosed space. Keywords: Hexachloroethane, White Phosphorus, Red Phosphorus, Toxic hazards. (AW)

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SUMMARY

Soldiers train in smoke. The health hazards of inhaling smoke have been made apparent by the toxicology data base that has been developed from testing of smokes in mammals and by the few documented instances of casualties resulting from unprotected exposure to smokes in training exercises. These hazards have led to the current masking policy which requires that the mask be carried by all troops when smoke is to be used and that the mask be worn at all times when troops are exposed to any concentration of hexachloroethane (HC) smoke or metal powder smoke or are operating in dense smoke of any type and whenever smoke is used in enclosed areas.

In order for the masking policy to serve its intended purpose of protecting the soldier from the hazards of inhaling smoke, the policy must be observed and enforced by commanders, the mask must be an effective filter for smoke particles, and it must remain effective. This raises a question about the rate at which the smoke particles clog the mask: how long can a soldier operate in smoke before inhalation resistance renders the mask ineffective? The U.S. Army Medical Research and Development Command (USAMRDC) was given responsibility to "Determine if the M17 protective mask is adequate to protect against Smokes/Obscurants" (Letter, HQDA OTSG, DASG-PSP-E, dated 20 Dec 85, subject: Health Hazard Assessment (HHA) Meeting, 3 Dec 85.). Since that task was originally defined, the M40 mask has been type classified, and the scope of the project was extended to include the protection afforded by the M40 mask.

This report summarizes the results of a study of existing information on the exposure of troops to smoke, the health hazards of the smoke, and particularly the ability of the M17 and M40 masks to protect the soldier against the hazards of exposure to military smokes and obscurants. The findings of the study are as follows:

The masking policy is necessary and the filtration capacity of the mask is sufficient to protect troops from the hazards of operating in smoke.

An alternative to the military mask for use with fog oil and diesel fuel smokes could be chosen from among the approved orinasal dust, fume, and mist respirators, but this type of protection would not be appropriate for HC, metal, or phosphorus smokes.

The greatest uncertainty in the assessment of health hazards from smoke and obscurants involves measurement of exposure, which determines the duration of effectiveness of the protection afforded by the mask in smoke.

Special precautions should be taken when employing HC smoke, which has caused fatalities when used improperly: the masking policy must be enforced, and HC should never be employed in an enclosed space.

INTRODUCTION

U.S. Army troops train under conditions similar to those of the modern battlefield,[1-4] and these conditions have specifically included the use of smokes and obscurants. The hazards of operating in smoke have been illustrated by incidents where soldiers have suffered casualties due to their unprotected exposure to smokes in training.[5,6] These incidents, and the health effects data base that has been developed in mammalian toxicologic evaluation of smokes, have led to the current policy (Message, Cdr AMCCOM, AMSMC-SFS, dated 10 Dec 85, subject: Smoke Safety):

> **Personnel will carry the protective mask when participating in exercises which include the use of smoke [and] personnel will mask:**
>
> **Before exposure to any concentration of smoke produced by M8 white smoke grenades or smoke pots (HC smoke) or metallic powder obscurants.**
>
> **When passing through or operating in dense (visibility less than 50 meters) smoke such as smoke blankets and smoke curtains.***
>
> **When operating in or passing through a smoke haze (visibility greater than 50 meters) and the duration of exposure will exceed 4 hours.**
>
> **Anytime exposure to smoke produces breathing difficulty, eye irritation, or discomfort. Such effects in one individual will serve as a signal for all similarly exposed personnel to mask.**
>
> **Personnel will mask when using smoke during military operations in enclosed spaces. Note: the protective mask is not effective in oxygen deficient atmospheres. Care must be taken not to enter confined spaces where oxygen may have been displaced.**
>
> **Smoke generator personnel will mask when it is impossible to stay upwind of the smoke.**

The U.S. Army Surgeon General has stated (Letter, HQDA OTSG, DASG-PSP-E, dated 27 Feb 85, subject: Issuance of Updated DA Policy for Use of Respiratory Protection when Using Large Area SMOKES/Obscurants.) that "...in view of the potential health hazards associated with exposure to HC SMOKE and to a lesser extent to any SMOKE/Obscurant, there is no reason to accept an elevated health risk when protective equipment is readily available in the form of the M17 protective mask."

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* See Table 4 for a listing of smoke concentrations that will decrease the transmission of visible light to 10 percent through a path length of 50 meters.

TOXICITY OF SMOKE

Health Hazard Assessment

The task of health hazard assessment has been broken down into three separate functions, the first two of which can each be performed independently of the other and the results combined to perform the last:

Define the health hazard. What are the consequences of exposure?

Define the exposure. Who is exposed, to what concentrations, and for how long?

Assess the overall risk. What are the likely consequences of the exposures in light of the health risks involved? What measures have been taken to eliminate or reduce exposure, and how effective are they?

The health hazard assessment procedure always consists of using the best data available and the best available methodology for interpreting it. New data and new insights into how to interpret the data can lead to new iterations of the process, and a better definition of the overall risk. After the health hazard assessment has been completed, the next step is to provide guidance that will make it possible to minimize the health risks involved.

Toxicity Assessment

In 1985, in response to a request from the Army Surgeon General, the U.S. Army Medical Bioengineering Research and Development Laboratory (USAMBRDL, now the U.S. Army Biomedical Research and Development Laboratory, USABRDL) reviewed the toxicology work performed up to that time on smokes. A Toxicity Review and an Exposure Review were included in that document, which is a widely-consulted source of information on health hazards to troops exposed to smokes and obscurants (2nd Endorsement, SGRD-UBG-M, U.S. Army Medical Bioengineering Research and Development Laboratory, dated 7 June 1985, subject: Health Risk Due to Exposure to Smoke/Obscurants). This document summarized, in the Toxicity Review section, the results of all of the smoke toxicity research performed up till that time under the direction of the USAMBRDL and others. Since that time, mammalian inhalation toxicology information has been developed for fog oil smokes,[7] for the yellow and green dye formulations used in the product-improved M18 smoke grenade,[8,9] and for some materials used in developmental smokes.[10] Genotoxicity information has also been developed for the red, violet, yellow, and green dyes used in the product-improved M18 grenade.[11,12] These studies have added to the knowledge of smoke toxicity, but there has been no information developed since the masking policy was issued that would require a modification of that policy.

EXPOSURE TO SMOKE

Definition of Troop Exposure

Soldiers are exposed to smoke under such a variety of conditions, produced by such a variety of means, that it has been difficult to define even the range of exposure. The definitions of a typical exposure, a worst-case exposure (one that not more than a specified small percentage of troops would ever experience) or a "worst-practicable-case" as used by Novak et al.[13] are even more elusive. Attempts to define exposure have been made using smoke deployment scenarios, counting the numbers of smoke grenades, pots, shells, etc., and using dispersion models to come up with an estimate of exposure which, depending upon the model used, could be an average or integrated exposure or a range of exposures correlated with the location of the exposed individual relative to the source of the smoke. Other models used the smoke concentrations that would produce the desired obscurant effect over an area.[14,15] A computer model for calculating the hazard due to chemical agents was modified to predict downwind dosage (concentration integrated over time) and deposition of obscurant materials.[16] This model requires input of meteorological or geographical and seasonal factors and data on the smoke system employed. There have been some field measurements of smoke exposure, but these have not been sufficient to produce a picture of the range of exposures to smokes that could be confidently used in health hazard assessment. And while the smoke concentrations at Smoke Weeks have been well-documented,[17,18] they don't represent field scenarios. The exposure review prepared in 1985 by the USAMBRDL had no better information upon which to rely than the same scattered measurements, models based upon smoke effectiveness or munitions usage in training scenarios, and calculations based upon the concentrations necessary to achieve the necessary obscuration that were used in other studies.

The lack of reliable exposure information is the weak link in health hazard assessment for many substances besides smoke and obscurants. A subgroup of the EPA Science Advisory Board, in a draft report dated December 7, 1987,[19] noted that risk assessments have "frequently been limited by the lack of reliable information on exposure....Experience has demonstrated that exposure assessment techniques are at a relatively less advanced state than are techniques for toxicity assessment...."

Modeling Based on Field Measurements

The conclusion that can be reached from reviewing the available information on exposure of troops to smokes and obscurants is that there is no better methodology available than one which uses atmospheric modeling to predict downwind concentrations based upon smoke usage in a particular scenario. This is also the consensus of the community that is involved in measuring the obscuration effectiveness of smoke. Since we will never be able to test for every condition, modeling must play a major role. Models must be tested and verified: the more field measurements we have which conform to a model, the more confidence we can place in the model.

Current Studies of Field Training Exposure

A study is currently being conducted by the USABRDL at the U.S. Army Chemical School, Fort McClellan, AL, to determine the extent of soldiers' exposure to fog oil and hexachloroethane (HC) smokes during training exercises.[20] Soldiers undergoing training are fitted with load-carrying equipment carrying sampling pumps and sampling media. General area samples are also being taken, including cascade impactor samples for determination of particle size distribution. Smoke exposure data will be correlated with the activity of the trainees, the duration of the exercise, the quantity and location of the smoke generating equipment, and the meteorological data that are being taken during the exercises. Future studies will involve sampling of soldiers' exposure during combat training scenarios. Some of the preliminary data from the Chemical School study are presented in Tables 1 and 2. Table 1 is derived from a series of measurements taken during an Operate and Maintain (O&M) training exercise using M3A4 fog oil generators at Fort McClellan, AL. The particular data shown were chosen because these were the highest fog oil concentrations encountered by the sampling team from USABRDL. The other available personal sampling data taken at the U.S. Army Chemical School are summarized in Table 2. If these data can be taken as representative, the O&M training activity, in which the smoke generators are intentionally set to malfunction and the operator must perform maintenance in order to generate smoke, involves an appreciably greater exposure to smoke than do the ordinary smoke activities during Advanced Individual Training.

There are very few data available for exposures of personnel to HC smoke. Those presented in Table 2 show a much lower smoke concentration on the personal samplers of the exposed personnel (who were masked) than the average encountered in the fog oil activities. Cascade samplers measured area concentrations of 0, 3, and 8 mg/m^3, with most of the particles having diameters below 2 μm (well within the respirable range).

Measurements of smoke deployed by standard U.S. Army smoke generators and smoke pots have been made at Camp Atterbury Reserve Forces Training Facility by Policastro et al.[21] A grid consisting of 50 sampling locations was laid out to measure plume behavior. Integrated and real-time measurements of concentration and particle size distribution were made, and meteorological measurements were also taken. The data will be used to evaluate models of smoke dispersion with the objective of improving the definition of soldier exposure to smoke. Some preliminary results from measurement of concentrations of fog oil generated by a single M3A4 smoke generator are summarized in Table 3. The peak concentrations in Table 3 lasted only a few seconds and are shown in order to demonstrate the variability with time of the expected exposure of soldiers to smoke. Policastro[21] states that "...the concept of small deviations about a relatively constant and well-defined mean concentration must be put aside in favor of the view that the plume is very inhomogeneous and highly intermittent." These data are presented to indicate the magnitude of average smoke concentrations that can be encountered in the field and the temporal variance of real-time concentrations. Policastro et al. have also performed similar experiments using HC smoke pots, but the data have not yet been made available.

TABLE 1. Fog Oil Concentrations During Operate and Maintain Training Exercise at Fort McClellan, AL[a]

Sample No.	Flow Rate LPM	Time Min.	Sample Mass mg/filter	Fog Oil Concentration mg/m³	Mask Deposition[b] mg/hr
124	3.503	40	1.0	7.1	17
123	3.476	40	1.0	7.2	17
117	3.521	40	1.4	9.9	24
102	3.552	40	2.5	17.6	42
126	3.480	40	3.4	24.4	59
112	3.505	40	3.6	25.7	62
121	3.479	40	4.3	30.9	74
128	3.493	40	5.0	35.8	86
120	3.501	40	5.8	41.4	99
130	3.549	40	8.3	58.5	140
114	3.515	40	8.9	63.3	152
127	3.485	40	9.4	67.4	162
109	3.486	40	10.1	72.4	174
119	3.488	40	10.2	73.1	175
101	3.520	40	10.9	77.4	186
105	3.475	40	16.6	119.4	287
129	3.517	40	17.0	120.8	290
103	3.525	40	17.7	125.5	301
110	3.508	40	17.7	126.1	303
111	3.509	40	20.8	148.2	356
116	3.517	40	22.0	156.4	375
106	3.482	40	26.5	190.3	457
115	3.543	40	30.2	213.1	511
104	3.520	40	64.7	459.5	1103
Mean				94.7	227
Standard Deviation				97.6	234

a. Personal sampling data taken 4 September 1987 at U.S. Army Chemical School O&M advanced individual training for chemical specialists (54B10). Only those samples that had a measured concentration are included. There were two samples that showed no exposure, and 2 filters were unaccounted for.

b. Mask loading calculated at breathing rate of 40 L/min. (heavy work[22]). This represents the maximum loading that could be anticipated at the measured smoke concentrations.

TABLE 2. Summary of Personal Sampler Data at U.S. Army Chemical School

DATE	ACTIVITY[a]	SAMPLING TIME min.	NO. OF SAMPLES	SMOKE CONCENTRATION mg/m^3 [b] MAXIMUM	MINIMUM	AVERAGE
04SEP87	O&M-54B10AIT	40	28	459	7	81
28JAN88	O&M-COBC	62	33	127	6	26
21MAR88	O&M-BNCOC/R	41	35	165	4	44
26AUG87	FTX-54B10AIT	92	25	55	8	24
01FEB88	FTX-COBC	52	30	26	3	3.4
24MAR88	FTX-BNCOC/R	40	35	15	1	1.5
03SEP87	54B10 E&I HC	18	3	2.1	1.0	1.6

a. O&M refers to operation and maintenance of intentionally malfunctioning M3A4 smoke generators. FTX refers to Field Training Exercises by smoke companies. The suffixes after the hyphen, 54B10AIT, COBC, and BNCOC/R, refer, respectively, to Chemical Specialists' Advanced Individual Training, Chemical Officers' Basic Course and Basic Non-commissioned Officers' Chemical Retraining Course. The last activity listed, 54B10 E&I HC, refers to employment and ignition of HC smoke pots; all other activities were with fog oil and the M3A4 generator.

b. Minimum concentration is the minimum non-zero concentration derived from the personal sampler filters. Average concentration includes the zero values from personnel who were engaged in the exercise and wore personal samplers.

TABLE 3. Mass Concentrations of Fog Oil from M3A4 Generator

Values Taken from Graphical Data Summaries of Policastro et al.[21]
Measurements Taken at 2-Meter Height, at Plume Centerline

Distance from source, meters	50	100	450
Average concentration mg/m^3	22	23	0.35
Peak concentration, mg/m^3	300	--	2

RESPIRATORY PROTECTION

Characterization of Exposure

Because of tactical and safety considerations, the most common exposures of soldiers to smoke are to fog oil and diesel smokes which can be categorized as not "immediately dangerous," defined in TB Med 502[23] as "a condition posing an immediate threat to life or health, or an immediate threat of severe exposure to contaminants likely to have adverse delayed effects on health..." In this situation, which does not apply to smoke in an enclosed area or to HC and metal smoke exposures, "...the consequences of respirator failure are lessened and emphasis can be placed on other factors such as long-term protection, convenience, cost, comfort, and wearer acceptance.... However, long-term protection should always be given priority over all other factors. Long-term protection is determined primarily by the amount of inward leakage of atmospheric contaminants during normal usage of the respirator...."

Military Protective Masks

A series of tests[24-27] was performed at the U.S. Army Chemical Research, Development and Engineering Center (USACRDEC) in the late 1970's and early 1980's, by a group headed by Robert W. Jolliffe, to evaluate the then-current mask, the M17A1, and its then-designated successor, the XM30 (equipped with the C-2 canister, which is used on the current M40 mask) against clogging by natural dusts, military obscurant smokes, decontaminants that could be aerosolized during use, and aerosolized materials designed as "smoke-breakers." These test reports, which are all classified CONFIDENTIAL, were designed primarily to test the ability of the masks to perform their primary function, protection against chemical warfare agents. The following discussion is based upon unclassified portions of these reports. Specific data on the action of materials upon the masks, such as could be used to attempt to apply the results of the USACRDEC tests to conditions other than those used in the mask tests, are classified CONFIDENTIAL, but the UNCLASSIFIED discussion can be used to support conclusions about the efficacy of the masks when they are challenged with smokes. The tests were performed in a manner consistent with the test procedures of the U.S. Public Health Service to evaluate the effectiveness of respiratory protective devices against liquid[28] and solid[29] aerosols and to measure the inspiratory[30] and expiratory[31] resistances of the masks and with the American Society for Testing and Materials Standard Method for Evaluation of Air Assay Media by the Monodisperse DOP (Dioctyl Phthalate) Smoke Test.[32] The draft NATO standard for respiratory protective masks[24] gave the criterion for acceptable inspiratory resistance: 80 mm H_2O at 80 liters/minute, corresponding to 6.0 cm $H_2O \cdot sec/L$.

<u>Testing procedures</u>. Test masks were mounted on a head form with a pressurized seal. The outlet of the mask was attached to a single-piston breather pump set at 36 cycles/min and 40 L/min, corresponding to the range of respiratory frequency and minute volume for a 70-kg man performing heavy work.[22] A tap behind the mask was connected to a pressure sensor (1-1000 mm Hg) and into an electronic manometer to measure pressure drops inside the mask during the respiratory cycle. The pump pulled "inhaled air" through the mask inlet

valve(s) and exhaled through an outlet diverter valve on the pump in order to provide greater deflection, and thus greater sensitivity for the pressure drop readings. The measures of filter effectiveness included protection factor (PF, defined as the ratio of the mass concentrations of the aerosol upstream and downstream from the filter) and resistance to breathing, both inspiration and expiration.

Solid particle smokes. When tested with solid particulates,[24] the XM30 mask equipped with the C2 canister was less sensitive to clogging than was the M17A1, due to the absence of any prefilter and to the almost three times greater surface area of the C2 canister compared to the filter of the M17A1 mask. When the M17A1 was equipped with rain caps and M4 winterization kits, a sharp tap upon the particle-laden filter cap with a hard object produced a rapid reduction in inspiratory resistance due to removal of much of the accumulated material. Results showed that the nature of the solid particles had a great effect upon the extent of clogging. The results of tests with specific materials are CONFIDENTIAL.

Phosphorus smokes. When tested against phosphorus smokes,[26] the loading that produced an unacceptable increase in clogging (as defined by the NATO standard) was 50 percent greater with the C2 canister than with that of the M17A1. The phosphoric acid aerosol produced by red phosphorus smoke can cause significant increases in protective mask inspiratory resistance when the mask-wearer is exposed to high concentrations for lengthy periods, but the phosphorus smokes are not normally employed in large-area screening operations where that combination of exposure conditions would be encountered. There exists the possibility, however, that personnel may be exposed to lower levels of phosphorus smoke for lengthy periods, enough for a substantial quantity of smoke to deposit on the protective mask filters, and the authors recommend that the filtering unit, including the M17A1's rain cap, be replaced after exposure either for extended periods or for repeated exposures to phosphorus smoke.

Oil smokes. Fog Oil (MIL-F-12070-1) and Diesel Fuel (MIL-F-461621-DF) were used to test the mask filters against oil smokes.[25] The generator was a turbo-gasoline engine fogger which produced average particle diameters of about 5 μm. (This is much larger than the sub-micrometer particles produced by the M3A4 fog oil generator or the vehicle engine exhaust smoke system and may make the study "risky-sided," according to the authors, since smaller particles would be more penetrating.) Concentrations used were 1.0-2.3 g/m^3 for fog oil and 2.0-6.0 g/m^3 for diesel fuel. Breakthrough, as measured by a hydrogen flame ionizer, occurred at a greater mass loading for the M17A1, with and without the cap, than with the XM30 with the C2 cartridge. Both masks were significantly less sensitive to clogging from challenge with oil smokes than from challenge with solid materials. In the case of the M17A1, the solids bridge across the prefilter and effectively clog it. Liquids coat and sink into the prefilter, producing less physical blockage for equivalent amounts of material. The same mechanism applies to the XM30, but here the primary filter is involved since no rain cap (prefilter) is employed. Tapping the C2 canisters left peak inspiratory resistance essentially unchanged, in contrast to results with solid materials, where significant decreases in inspiratory resistance were obtained by striking the clogged filter to

dislodge collected material. The conclusions of the oil smoke study were: (1) For troops exposed to moderate or high concentrations of screening clouds for extended periods, addition of the M4 kit to the M17A1 protective mask is recommended. If this produces heavy loading, the M4 kit can then be removed to provide an additional period of protection. (2) For the XM30 mask, the filter may be protected with a suitable (unspecified) field expedient, or the canister can be replaced. (3) Exposure to a dust cloud concurrently or subsequent to exposure to an oil smoke cloud did not result in a detrimental increase in dust clogging rate. Since the C2 filter was used in the tests with the XM30 mask, the conclusions regarding its effectiveness are applicable to the M40 as well.

Interpretation of test results. The purpose of the tests at the USACRDEC was to evaluate the ability of the masks to provide protection against the chemical and biological agents that they are designed as countermeasures for, when smoke is used either prior to or coincident with chemical agents. This is a more severe criterion than the ability of the mask to protect against the health hazards of the smoke itself, which manifest themselves at much higher concentrations than is the case with chemical warfare agents. Data and conclusions regarding effects of specific materials on the efficacy of the masks are classified CONFIDENTIAL. The tests on the M17A1 and the XM30 masks showed that there is a definite increase in inspiratory resistance to be expected when the masks are used in smoke. The effect was more pronounced (occurring at lower levels of particulate loading) with smokes consisting of solid particles than with those formed of liquid droplets, but the clogging was more reversible in the case of solids than in the case of the liquids. The authors concluded, however, that unacceptable clogging effects were obtained only with aerosols of other than standard military smokes or with higher-than-expected concentrations of military smokes.[26]

Other tests. Lee and Curtis[33] measured protection factors of the C2 canisters(used in the M40 mask) and the M13A2 filters(used in the M17A1 mask) in cold (-40°F) and under humid and dry conditions at 70°F. They found no difference in PF due to cold or humidity. The C2 filter out-performed the M13A2 by at least a factor of 10 under all conditions. Aerosols were dioctyl phthalate (DOP), produced using a Liu and Lee[34] generator, with a mass median aerodynamic diameter of 0.08 μm, and 5-μm nickel particles obtained commercially. The filters were tested in a straight-through flow at 5, 10, and 20 L/min and at cyclic flow of 20 and 60 L/min (peak flows of 70 and 170 L/min, respectively).

Loading of mask. Although it is difficult to define the range of concentrations to which individual soldiers may be exposed, and thus the degree of loading that they may receive on filters of their protective masks, Table 4 represents predicted loading under conditions ranging from very dense smoke (visibility of 10 meters) through smoke that is just dense enough to be called "dense smoke" (50 meters visibility), to minimally effective smoke (200 meters visibility). The number of hours that a mask could be used under any of these conditions depends upon the rate of loading and the inspiratory resistance increase per unit of mass of each type of smoke. These latter values are CONFIDENTIAL, and can be found in the reports by Jolliffe and Allen for oil smokes[25] and for phosphorus smokes.[26]

TABLE 4. Loading of Mask by Standard Smokes

Concentrations Calculated from Beer-Lambert Law
Based upon Degree of Obscuration as Measured by Depth of Visibility

SMOKE	Extinction Coefficient[a] (m^2/g)	Visibility[b] (meters)	Concentration (mg/m^3)	Loading Rate[c] (mg/hr)
Fog Oil (SGF-2)	7.44	10	30.95	74.28
		50	6.19	14.86
		200	1.55	3.71
Diesel Fuel (DF-2)	5.84	10	39.43	94.63
		50	7.89	18.93
		200	1.97	4.73
Phosphorus Smoke (50 % R.H)	3.71	10	62.06	148.95
		50	12.41	29.79
		200	3.10	7.45
Hexachloroethane Smoke (85 % R.H.)	3.33	10	69.19	166.05
		50	13.84	33.21
		200	3.46	8.30

a. Extinction coefficients at a wavelength of 0.6 μm from Milham and Anderson[14].

b. Visibility defined as the path length for 10 percent transmission at the concentration determined by the Beer-Lambert Law.

c. The loading rate is calculated assuming that the soldier is breathing at a constant rate of 40 liters/minute (heavy work).

The average concentrations measured by Policastro et al.[21] and summarized in Table 3 are in the range of dense smoke at the 50 and 100 meter distances and the 100-meter centerline concentration would involve a loading rate of 53 mg/hr on the mask filter. The concentrations measured at the U.S. Army Chemical School and summarized in Table 2 involve instances of heavier loading, especially during the O&M activities. The sampling times given in Table 2 were those of the duration of the training activity. The loading on the mask under the most severe circumstances encountered at the Chemical School (459 mg/m^3 for 40 minutes) would cause a measurable but not unacceptable increase in inspiratory resistance in either the M17A1 or the M40 mask.

Alternative Respiratory Protection

The M40 protective mask and its predecessor the M17A1 were not designed for the purpose of protecting against smoke. The policy of requiring the use of the mask to protect against the hazards of inhaling smoke is an expedient: Soldiers take the mask into the field, so it is available for the purpose. Another type of device might work better in smoke and not be as much of a physical and psychological burden upon the soldier. There may be a place for a simpler respiratory mask to be used in smoke training exercises such as those conducted for smoke companies, but before the soldier and the system are burdened by adding another piece of equipment, its advantages must be made clear.

The National Institute for Occupational Safety and Health (NIOSH) is charged under Public Law 91-586 to develop and periodically revise recommendations for limits of exposure to potentially hazardous substances in the workplace. It also recommends preventive measures designed to reduce or eliminate adverse health effects of these hazards. In formulating these recommendations, NIOSH evaluates all known and available scientific information relevant to the potential hazard.[35] NIOSH has published guidelines[36] for selecting respiratory protection and has also included respirator selection guidance in its Pocket Guide to Chemical Hazards.[37] No IDLH (Immediately Dangerous to Life and Health) level has been established by NIOSH for phosphoric acid, the major component of phosphorus smokes. For zinc chloride fumes, the major ingredient of HC smoke, the IDLH limit is 2000 mg/m^3. The NIOSH decision logic "...identifies the criteria necessary to determine the classes of respirators that will provide a known degree of respiratory protection for a given work environment, assuming that the respirators are used correctly."[36] The user of the decision logic answers a set of questions concerning the situation in which the respirator is to be used and the contaminant to which the wearer is to be exposed. Exposure to phosphorus smokes and ordinary exposures to HC smokes do not involve IDLH concentrations, but both of these smokes are eye irritants, and would, under the NIOSH guidelines, require the use of a full face mask. There is thus no benefit to be gained from introducing another respiratory protection device for use with these smokes. Brass powder smokes tested positive for eye irritancy in two studies,[38,39] being graded "mildly irritating" in one[37] and "moderately irritating" (one grade higher than "mildly irritating") in the other study[39]. Full face protection, such as is provided by the military mask, is indicated in this case also.

Fog oil and diesel fuel were not found to be eye irritants[38] and have no IDLH levels[37], so an orinasal respirator may be an option when exposure is known to be limited to these smokes. The use of such a mask would eliminate most of the restrictions of the wearer's field of vision associated with the full facepiece mask. A large number of orinasal dust, fume, and mist respirators are listed in Table 2 of TB Med 502[23], and one of these could be chosen for use in standard, repetitive training exercises, using only fog oil or diesel fuel smoke, such as some of those conducted during training of smoke companies at the U.S. Army Chemical School. However, the limited application

of any mask chosen would weigh heavily against its adoption: it could not be used in any situation considered immediately dangerous to life and health or where there is a substantial probability of eye irritation.

Another option that could be applied in training is a filter canister without the organic vapor-removing carbon--for use in exposures to smokes that do not have an appreciable vapor component. The initial inspiratory resistance of such a canister would ordinarily be lower than that of one containing granular carbon, but the performance characteristics under load would have to be determined in tests similar to those performed by Jolliffe et al.[27] If such a training canister were to be adopted, measures would have to be taken to prevent the possibility of its inadvertent use in cases where vapor removal is required.

CONCLUSIONS

Effectiveness of the Mask

The questions of most concern to the Army, from the viewpoint of those who have responsibility for protecting the soldier from undue hazards, from those whose responsibility is to accomplish the mission, and from the individual soldiers who must operate in the smoke environment, are:

Are there hazards from exposure to smoke and obscurants?

Does the mask provide adequate protection against these hazards?

Both questions must be answered in the affirmative. There are many gaps in our knowledge of the health hazards of smokes and obscurants, and there is not a good definition of the exposure which must be protected against. But the weight of the evidence is on the side of prudence.

The masking policy, if enforced in training scenarios, is necessary, and the filtration provided by the mask is sufficient to protect the soldier from the hazards of exposure to smokes. The loading rates, even in very dense smoke limiting visibility to 10 meters, are such that the mask will be effective for several hours.

Exceptionally High Smoke Concentrations

The protection afforded by the mask is generally sufficient for normal exposures to smoke, for several hours at the concentrations calculated in Table 3 and the measured concentrations presented in Tables 1 and 2. In situations where the concentrations are many times those in the tables, and particularly in the case of ultrahigh concentrations of HC smoke, the mask's protection may be short-lived. Such concentrations ordinarily exist for only brief periods of time except where smoke is employed in enclosed areas. Where these very high concentrations of smoke are present for a longer time period, the protection afforded by the mask will be overwhelmed and the mask should be used only as a device to offer protection while escaping from the concentrated smoke. A full face, high efficiency gas mask such as the M17A1 or the M40 is approved by the National Institute for Occupational Safety and Health[36] for use as an escape device in case of high level exposures to zinc chloride aerosols that are the primary acute hazard of HC smoke, mineral oil mists such as fog oil and diesel fuel smokes, and phosphoric acid mist such as that produced by red or white phosphorus munitions.

Alternatives to the Military Mask

An alternative to the military mask for use with fog oil and diesel fuel smokes could be chosen from among the approved orinasal dust, fume, and mist respirators, but this type of protection would not be appropriate for metal or phosphorus smokes which can cause eye irritation or for HC smoke which is also an eye irritant and can be immediately dangerous to life and health at sufficient concentrations. The option of not wearing the mask in situations where it is doctrinally required has been exercised, according to anecdotal

reports,[13] but cannot be recommended. When, in the judgment of a unit commander, the use of the mask will present a greater safety hazard than will result from unprotected exposure to smoke, or adherence to the masking policy will prevent the accomplishment of the mission, the commander may consider the non-masking option. But this decision should never be made arbitrarily or for trivial reasons.

Canister Replacement

An important conclusion that can be drawn from the studies at the U.S. Army Chemical Research and Development Center[25,26] is that after the mask is used in a dense smoke or in a lengthy or repeated exposure to smoke, it will be necessary to replace the filter of the M17A1 mask or the canister on the M40. This is most important in the case of exposure to any of the smokes consisting of liquid droplets, especially those of hygroscopic acids, i.e., phosphorus and HC smokes.

Smoke Exposure

The weakest link in the chain of hazard assessment for smoke/obscurants exposure is the quantification of exposure. Exposure must be defined using models, and field exposure data must be made available to test and verify the models. Definitive information on troop exposures in some standard training scenarios should result from tests that are currently being conducted by the USABRDL.[20,21]

Special Precautions with HC Smoke

The most recent fatalities that have been reported using HC smoke have occurred to unmasked individuals entering enclosed areas where HC smoke was employed.[5,6] These incidents reinforce two of the the recommendations made by Cichowicz[40] in 1983:

> Enforce the Army directive to mask in the presence of HC smoke.
>
> Under no conditions should HC be deployed indoors or in confined quarters.

Deploying HC or any other smoke in an enclosed area can rapidly produce smoke concentrations that are beyond any considered in the studies of respiratory protection afforded by the military mask.

Non-quantifiable Considerations

Other questions remain. The wearing of the mask stresses the soldier both physically and psychologically, it disrupts normal communications, it decreases his range of vision, and it increases the labor of breathing--all of which can lead to performance degradation and can also increase the risk of accidental injury. Although they are almost impossible to quantify, these are real risks that must be taken into account when planning exercises in which soldiers will be exposed to smoke.

RECOMMENDATIONS

1. The current policy requiring that the mask be carried by soldiers who may be exposed to smoke and that the mask be worn in health-threatening smoke atmospheres is a necessary measure and should be vigorously enforced.

2. Research to quantify soldiers' exposure to smoke during training exercises will result in a better definition of the situations when masking is necessary and will provide information to determine the margin of protection afforded by the mask. These efforts should be continued.

3. The zinc chloride aerosol produced when deploying HC smoke has caused fatalities in unmasked personnel exposed to high concentrations for short periods of time. The masking policy should be enforced without exception when HC smoke is employed, and HC smoke should never be deployed in a confined area.

4. While the M17A1 and the M40 masks can provide protection during normal tactical smoke scenarios, they should not be relied upon for long term protection from ultrahigh smoke concentrations--as when smoke may be employed in enclosed areas. In such a situation, the mask should be used only to provide protection while escaping from the area of concentrated smoke.

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